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Technical and economical evaluation of a high-temperature air heater intended for integrated gasification combined cycle unit

N V Valtsev¹ and A F Ryzhkov¹

¹ Ural Federal University
Russia, 620002 Yekaterinburg, Mira, 19

nvaltsev@mail.ru

Abstract. In this paper the costs of creating a high-temperature air heater intended for the integrated gasification combined cycle unit developed by the authors are estimated and are compared with a steam boiler. The results can be used not only in the further development of the integrated gasification combined cycle plant under consideration, but also be interesting to specialists involved in the development of various high-temperature heat exchangers.

1. Introduction

Despite the plans of Europe and the USA to reduce the use of coal, the world's coal generating capacities continue to increase, mainly due to Asian countries. One of the promising ways for the development of coal energy is integrated gasification combined cycle (IGCC), which can increase the efficiency of electricity generation and at the same time significantly reduce harmful emissions into the environment.

In this article, a feasibility study of a high-temperature air heater used in the scheme of IGCC described in [1] is carried out. The air heater is a pulverized coal-fired boiler, in the heating surfaces of which air with a pressure of 1.8 MPa after a compressor is heated from 450°C to 900°C before being fed into the combustion chamber of a gas turbine, the air flow is 553 kg/s. The use of an air heater makes it possible to reduce the gasification island of IGCC up to 30%, and also, according to the calculations, to reduce the total coal consumption of IGCC by 15%.

2. The importance of the economic component in the design of high-temperature units

Along with technological problems, an important, and possibly decisive factor in the development of various high-temperature heat exchangers is their high cost, determined by the need to use expensive heat-resistant alloys. The cost of nickel alloys that are widely used now can reach up to 70\$ per kg for alloys of type 740 or 282 and even higher [2] with the cost of low-alloy steel 2-3\$, and austenitic steel 7-10\$ per kg. Thus, when designing high-temperature heat exchangers, the first priority, which prevails, for example, over the convenience of placing heating surfaces, becomes the maximum possible reduction in the weight of the high-temperature part and the reduction in the length of the outlet pipelines. That puts developers in a tight framework of maintaining cost in a moderate range while all technological requirements are met.

To reduce the cost, it is advisable to divide the unit into a number of temperature zones using various materials in them and switching to expensive alloys last. Based on the indicated prices for steels and alloys, the cost of the high-temperature part may exceed the cost of the rest of the heat



exchanger, therefore, the task of minimizing its weight should be considered as a priority, further adjusting the design of the remaining parts to it.

An obvious way to reduce it is the transition to the use of pipes of small diameter, which will significantly reduce the required wall thickness of the heating surface. According to the calculations made by the authors in [3], a decrease in the internal diameter from 50 to 10 mm reduces the cost of the heating surface by about 3 times.

On the other hand, to reduce the dimensions of the high-temperature part, it is necessary to intensify heat transfer, for which it is advisable to place it in the high-temperature zone, while ensuring reliable operation of the pipes, due to the high heat transfer coefficient from the side of the working fluid.

3. Alloys for a high-temperature air heater

The selection of alloys for a high-temperature air heater was considered by the authors earlier in [3]. It is worth noting that the domestic industry does not produce pipes from such alloys, with the exception of the CrNi55MoWZr alloy, designed for use in high-temperature gas reactors. Also additional studies are required to assess the behavior of such alloys, designed primarily for the needs of the gas turbine industry, in the environment of coal combustion products, or even the development of new alloys based on the results of the study. For an initial assessment of the behaviour of nickel alloys under such conditions, a test was carried out in which the CrNi60WTi alloy tube was selected from the products manufactured by the domestic industry, and samples, including those with additional protective coatings, were placed on the ash protection structures of the primary steam superheater of the pulverized coal-fired boiler (figure 1). Test duration was 3000 h at the local flue gas temperature of about 900°C.



Figure 1. Samples in the boiler during testing.

Unfortunately, due to limitations associated with the COVID-19 pandemic, it has not yet been possible to complete the analysis of the samples, but according to initial estimates, it can be said that the samples, both without coating and with NiCrAlYTa coating, did not undergo noticeable ash and corrosion wear. The coating with the addition of CrB₂ did not withstand the working conditions and exfoliated. Thus, the use of existing domestic heat-resistant nickel alloys in a pulverized-coal boiler environment can be considered as realistic.

4. Air heater designing and its cost estimation

Initially, when developing a high-temperature air heater, the experience of similar installations built in different countries in the middle of the last century, for example [4], was considered. However, the air

heating in them was carried out to about 700°C, not to 900°C, as in the designed unit, and after analysing the cost component, the inexpediency of creating the installation in a similar way, as was supposed in the 90s in the USA during the HiPPS project [5], became apparent.

The transition to pipes of small diameter leads to the need to solve the problem of placing a large number of sufficiently short (about 8 m length) parallel-connected pipes. In addition, the small length of the pipes does not allow to divide the heating surface into a large number of sections. Therefore, it was decided to distinguish two zones: high-temperature, located in the furnace, and low-temperature, located in the convective gas pass. As a result, a design with sectioning the furnace with screens was proposed, that allows placing a large number of short parallel-connected pipes in the constant volume (figure 2). The CrNi55WMoTiCoAl alloy was chosen for the calculations as the material of the high-temperature part, and 12Cr18Ni10Ti steel for the low-temperature part. The cost of materials is 5000 rubles per kg and 500 rubles per kg, respectively.

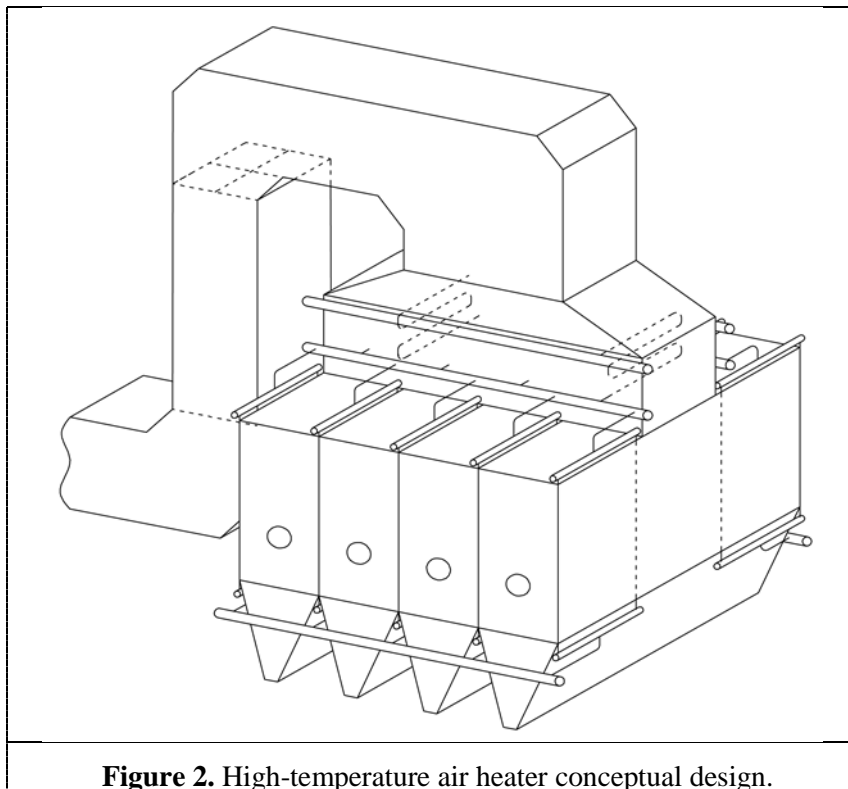


Figure 2. High-temperature air heater conceptual design.

According to the results of the calculation, the main parameters of a high-temperature air heater are presented in table 1.

Compare these data with a supercritical steam pulverized coal-fired boiler using the PK-39 boiler of 300 MW unit as an example. When converted to the same usable heat, we get that the total heating surface area of the PK-39 boiler is about 25% larger and their mass is 2.4 times larger than of high-temperature air heater, which will give the total cost of heating surfaces at an average cost of boiler steel of 200 rubles / kg in 4.9 times less than for an air boiler of the same heat power. A noticeable decrease in the cost of an air boiler can be achieved only by lowering the temperature of air heating to the level of 780-800°C and switching to the use of cheaper structural materials, in this embodiment, the cost of heating surfaces will decrease by about 2.5 times.

Table 1. The main parameters of a high-temperature air heater.

Parameter	Value
Useful heat, MW	286.5
Compressed air inlet/outlet temperature, °C	450/900
Compressed air pressure, MPa	1.8
Compressed air flow, kg/s	553
Fuel	Kuzbass coal 1SS
Fuel consumption, kg/s	13.4
Boiler efficiency (gross), %	91.5
heating surfaces material, diameter/thickness, mm	
high-temperature	CrNi55WMoTiCoAl, 19/2.2
low-temperature	12Cr18Ni10Ti, 60/2.8
Area/cost of boiler heating surfaces, m ² / mln. rubles	
high-temperature	3930/365.8
low-temperature	4360/48.2
total	8290/414

5. Conclusion

At the moment, against the backdrop of the crisis, there is a noticeable reduction in natural gas prices, which will certainly put pressure on coal as energy fuel. Nevertheless, integrated gasification combined cycle plants continue to be a promising direction in the development of coal energy. The variant of such a combined cycle plant with an external air heater considered in the article is one of the options for increasing the efficiency of the installation. However, the cost of an air heater with air heating to 900°C was shown to be high, so the choice of the optimal heating temperature requires more careful justification. It seems appropriate to reduce the heating temperature to 800°C, which will reduce the cost of the apparatus by 2.5 times.

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